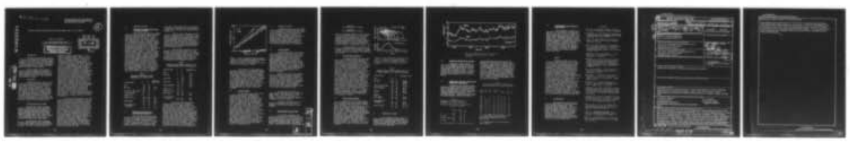
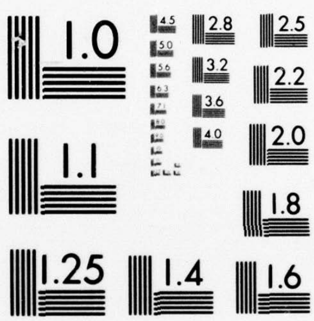
AD-A053 541 AIR FORCE GEOPHYSICS LAB HANSCOM AFB MASS F/G 4/2
ANALYSIS OF PARTICLE SPECTRAL DATA FROM OPTICAL ARRAY (PMS) 1D --ETC(U)
1978 R M CUNNINGHAM
UNCLASSIFIED AFGL-TR-78-0102 NL

1 OF 1
AD
A053541



END
DATE
FILMED
6 -78
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3

Reprinted from Preprint Volume: Fourth Symposium on Meteorological Observations and Instrumentation, Apr. 10-14, 1978, Denver, Colo. Published by the American Meteorological Society, Boston, Mass.

ANALYSIS OF PARTICLE SPECTRAL DATA FROM OPTICAL ARRAY (PMS) 1D AND 2D SENSORS

Robert M. Cunningham

Air Force Geophysics Laboratory
Hanscom Air Force Base, Bedford, MA 01731

1. INTRODUCTION

The days of laborious hand extraction of particle size distribution information, parti-by particle, are largely over. Now that automatic equipment "snows" us with numbers we must learn - or teach the computer - how to extract meaningful values from this avalanche of data. This paper reports on efforts in this direction.

With the advent of such copious particle data it is becoming more realistic to plan for and obtain independent measurements of related parameters both from aircraft and from remote sensors on the ground. Some comparisons of this nature are given.

2. DATA SOURCE

For several years the AFGL has flown a full set of Particle Measuring Systems, Inc. (PMS) sensors aboard both a C-130 (AF Operated) and a Learjet (contractor operated). Many flights have been made through U.S. east coast deep cyclonic systems as well as into tropical cloud systems. A variety of hydrometeor types has been encountered. Many of these aircraft data samples were accompanied by measurements of the radar reflectivity factor just ahead or behind the aircraft made by a ground based radar, as well as measurements of the water content and particles by other airborne instrumentation.

3. THE PMS OPTICAL ARRAY PROBES

The PMS optical array instruments, and their calibration and to some extent data analysis have been described and discussed in a number of publications, reports and preprints, such as Knollenberg (1970)(1972)(1975) (1976), Heymsfield and Knollenberg (1972), Heymsfield (1976), Cunningham (1976), Gayet (1976). Aspects of the design which relate to the analysis procedures described in this paper follow.

A vertical laser beam illuminates through an optical system a line of photodiodes, 24 in the case of AFGL's 1D probes and 32 for the 2D probes. Particles on passing through this beam cast a shadow on these diodes. If the shadow is complete enough to reduce the output level of the diode circuit by 1/2 then this diode is considered occluded. In one set of instruments, the 1D's, the maximum number of diodes occluded during the passage of a particle is recorded as particle size. In the other set, the 2D's, a rapid scanning system is used to allow the recording of the diodes occluded per 25μm (cloud probe) or 200μm (precip. probe) forward motion of the aircraft. A pictograph of the particle can be produced after suitable data processing of this latter type of information. The end diodes in 1D devices are used to indicate oversize particles which permits, through suitable design, the electronic hardware to reject particles which are only partly sampled. This same problem is handled, in the case of the 2D devices, by a subsequent software routine. Unfortunately, with this edge reject requirement sample volume decreases with increasing particle size. Schemes can be devised, which so far require visual examination of the particle, that could estimate particle size from the pictograph of a portion of the particle and thus retain the full sample volume for the larger fewer particles. It has not been found practical, particularly for irregular particles, to pursue this approach.

The three length dimensions that make up the sample volume are determined by; one, the length of the diode array divided by the magnification and adjusted for the end reject feature; two, the distance of exposure of the laser beam to the free flowing air and particle stream, adjusted for a depth of field factor for the small particles and; three the length corresponding to the chosen sample time multiplied by true airspeed. Length one and three are determined with ease as long as the magnification of the optics is checked frequently and good true airspeed values are available. The second length has been the subject of some debate because of the requirement in the smaller channel sizes for depth of field information. Irregular particles with thin arms or particles with large aspect rations may present a problem. In our present analysis we have used the depth of field values given by the manufacturer, PMS.

4. ANALYSIS OF 1D DATA

4.1 Adjustment for Quantization and for Non Spherical Shapes

Several analytical steps are required before the counts per channel output of the PMS circuitry can be processed into meaningful particle distribution information. First the basic magnification of the optical imaging system must be known. This is frequently checked, and adjusted if needed, by passing a length of wire of known size through the beam. Because the particle size information is derived from discrete steps and because there is some lost space between photodiodes there is a quantization correction to be applied even in the case of spherical particles (rain). In the case of non spherical shapes, irregular or regular, further corrections are needed. A study of the corrections required to allow conversion from recorded channel (diode) number to maximum particle size was supported by AFGL and made by Knollenberg (1975). The conversion equations for the particle types used in the AFGL storm flights have been derived in part from this study and incorporated into our software. Types "Plate family" and Aggregates of Plates and dendrites have recently been added to the relations listed for these, being estimates using the standard more pristine types as a guide. The equations being used by AFGL-LY are listed in Table 1.

Table 1

Adjustment of PMS Channel Number
Adjusted Ch # = * Ind. Ch # + B

Particle Type	M	B	Breakpoint (Ind. Ch #)
Rain	.99	.18	-
Wet Snow	.99	.18	LE 2
" "	1.15	.18	GT 2
Large Snow, Small Snow	1.15	.18	-
Bullet-Rosettes	1.02	.32	-
Columns (4:1)	1.3	.76	-
Needles (7.5:1)	.20	3.04	LE 1
" "	1.28	1.08	GT 1
Plate Family	.94	.55	LE 3
" "	1.08	.02	GT 3
Agg. Plates and Dendrites	.94	.55	LE 3
" " " "	1.20	-.44	GT 3

4.2 Conversion of Crystal Size to Equivalent Melted Diameter

Use of the above relations permits analysis of the "cloud" and "precip" PMS probe raw counts to determine particle spectra in for instance, the form of maximum physical size vs number of particles per cu meter. In order to derive normalized particle spectrum, mass spectrum or total ice or liquid water content (IWC, LWC) or radar reflectivity (Z) an additional conversion is required, that of maximum size to mass or more conveniently to equivalent melted diameter (D).

There is now a considerable literature reporting on such relations. Unfortunately, the data set is somewhat biased toward single pristeen crystal measurements and rimmed particles. It is also geographically biased toward mountain snow systems and against deep cyclonic storm cases. A listing of the several sources and illustrations showing some of the relations found between maximum length and particle mass has recently been given by Heymsfield (1976).

From the above noted sources, and a few others, a set of power functions has been derived. Those found most useful in our analysis of east coast deep storm clouds are given in Table 2. Three rather different particle type L to D relations are also shown in Fig. 1 along with marks denoting the original channel center size and adjusted size for channels 1, 5 and 15.

Table 2

Equations used to Convert Particle Size (L) to Melted Diameter (D), $D = AL^B$ Units, mm.

Particle Type	A	B	Breakpoint (L)
Rain	1	1	-
Wet Snow	1	1	LE 1
" "	1	.65	GT 1
Large Snow	.4	.78	LE 1
" "	.4	.88	GT 1
Small Snow	.4	.78	LE.5
" "	.37	.67	GT.5
Bullet-Rosettes	.26	.67	LE.2
" "	.44	1.0	GT.2
Columns (4:1)	.44	1.0	-
Needles (7.5:1)	.26	.67	-
Plate Family	.34	.78	LE 1
" "	.34	.68	GT 1
Agg. Plates and Dendrites	.34	.78	LE 1
" " " "	.34	.68	GT 1

Two rather broadly defined snow classes not found explicitly in standard classifications, i.e., Magono and Lee (1966) are large snow (LS) and small snow (SS). It was found in practice, particularly when probing deep cyclonic systems that these types best describe the snow and snow aggregates that could be identified from a rapidly moving instrumented aircraft. This simplification is necessary only in part because of the nature of the observation platform. When dendrites, plates or needles were encountered they could in fact be identified from the aircraft on the so called "snow stick" or on the 2D real time CRT display. It had also been found in our work with IWC and radar Z correlations to be useful to lump several of the available relations into these two categories.

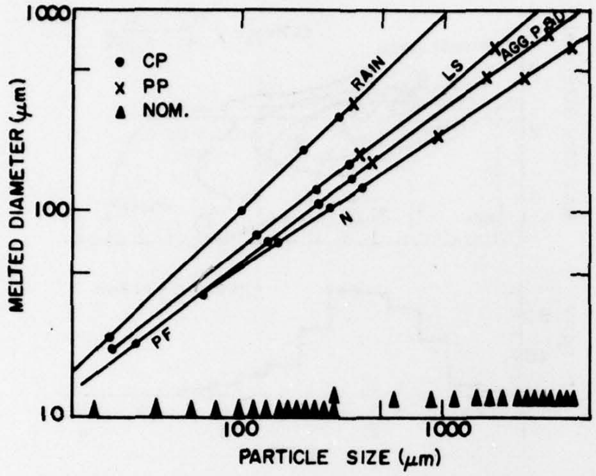


Figure 1. Plots of conversion relations between particle size (L) and Melted Diameter (D) Original channel size multiplied by diode width is indicated on L axis. CP, cloud probe, PP; precip probe; PF, plate family; N, needles.

The class LS is loosely defined as aggregates of many plates and undefined crystals. Large snow clusters (cm. in size) often found in and just above the melting layer (in the radar 'bright band') probably should not be classed as LS, but deserve a class by themselves, this has not been defined as yet. One reason for suggesting a separate class of large snow clusters is that it would probably have a Z to M relation significantly different than that used for LS or single crystal types. The class SS is also loosely described as undefined single crystals or aggregates made up of only a few single crystals.

4.3 1D Output Format

The one second count in each of the 15 channels of each probe is summed for a preselected time period. Four seconds is usually chosen for this time period as this is roughly the time it takes the aircraft to fly through one sample volume of the ground radar. Based on calculations of Joss and Waldvogel (1969) the sample volume swept out in four sec. by the PMS optical array probes is not a sufficient sample size for the larger particles of each sensors range. In order to obtain an improved distribution function we have usually combined the four sec. samples into 5 min. "run" samples normalizing the four sec. data in a manner suggested by Sekhon and Srivastava (1970). The results of such a treatment have been illustrated by Cunningham (1976). It should be noted that the computed water content and even radar reflectivity values from the four sec. sample appear, however, to give meaningful and not particularly statistically noisy values. See Fig. 1, Cunningham (1976).

5. ANALYSIS OF 2D DATA

As discussed above the 2D data format contains information on the shadow of the particle in two dimensions, one along the effective plane of the diodes the other in the direction of flight. A number of types of output can be derived from this information, the type usually presented is the direct pictograph of the particle shadow. We have chosen to use this presentation and several others. Before deriving the more sophisticated parameters an edit program has been found to be a necessity.

5.1 2D Edit Program

The pictograph output is very useful without any editing of the data as one's 'eye' is very generous in its ability to automatically throw out extraneous noise, malfunctions, or usually unwanted effects from, for instance, partly transparent crystals. Programs have been written to indicate the occurrence of malfunctioning diodes, to eliminate particles when splashing or breakup occur, and to fill central holes in particle images. This becomes a problem with rain data as well as with transparent ice particles as rain drops transmit light which often results in an apparent hole in the particle pictograph.

Several other 'fixes' are necessary. Time is required for triggering the scanning circuits as the particle begins to shadow the diode array. Thus part of the particle is not included in the final pictograph. A correction has been added in the software that compensates for this missing part. Area is added as a fraction of the number of diodes shadowed on the first real scan, alternately adding one scan or two scans to each successive frame.

At times drops hit some of the sensor structure and then enter the illuminated sample region. These drops appear as long streaks. They are partly eliminated in the analysis by rejecting all particles larger than 32 diodes in the 'time' direction.

Finally the equivalent of the end diode reject procedure, built into the 1D hardware, is in this case included in the 2D software.

5.2 Size Determined in Three Ways

In our present procedures three particle size parameters are computed; one, the equivalent of the 1D size; two, an approximation of the maximum length of the particle shadow on the horizontal plane and; three, the area of the shadow in the horizontal plane. The maximum length is approximated by the following expression

$$(X + \sqrt{X^2+Y^2})/2 \quad \text{if } X>Y \; ;$$

$$(Y + \sqrt{X^2+Y^2})/2 \quad \text{if } Y>X$$

where X is the maximum number of diodes shadowed in the horizontal direction and Y is the maximum number of scans shadowed in the flight direction. Analytical experiments with more sophisticated derivations of a maximum length of irregular shapes show that this simple formula is quite adequate. If the particle type is noted as rain, just the average of X and Y is used.

The area shadowed by the particle is conveniently obtained by just scanning the diodes occluded on each scan, after the editing programs mentioned above have been applied, then determining the total sum.

5.3 Derived Shape Parameters

Two shape parameters have been under study. One is a measure of edge complexity of the particle, i.e., the ratio of the average projected size of the pictograph vs its perimeter has been named average projection ratio. The other is called the equivalent circle ratio (ECR) and is the ratio of the perimeter of the pictograph to its area divided by the ratio of the perimeter of a circle to its area, the areas being equal. These ratios are computed for each sample run (about 5 minutes) and tabulated against the maximum size parameter. These tables are being studied to determine the feasibility of using such shape functions to determine snow type automatically. Snow particle shapes, modeled after the patterns used by Knollenberg (1975) were made for several sizes, relative to the 32 diode 2D dimension, and the above ratios determined from a 32x32 matrix of squares for various equivalent maximum sizes and orientations of the particle. The more significant ratio appears to be the ECR. Curves of its value vs maximum size are shown in Fig. 2. An example of 2D data superimposed on these dashed lines indicates that in this case the preponderance of snow type was LS and SS.

5.4 Area to Melted Diameter

Particle area, or at least the projected horizontal area, can as has been mentioned, be calculated using the 2D output. Calculations, independent of our previous L to D conversion, can then be made to determine particle mass or melted diameter. Relations between particle area and mass are required as very few were available Some were obtained by reformating work by Auer (1971). New data were obtained from Knollenberg (1976). From these two sources a selection of particle types was made that showed distinct differences. Some additional functions were added for types which exist over a limited size span, i.e., wet snow, through reference to their L to D relations. The resulting relations for these selected types are given in Table 3.

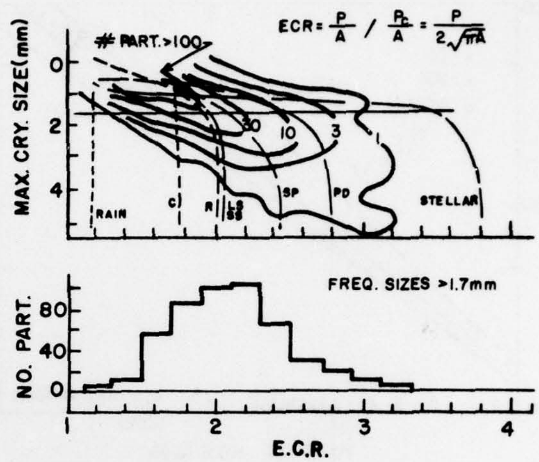


Figure 2. Plot of equivalent circle ratio (ECR) vs maximum crystal size for nominal crystal shapes: C, columns; R, rosettes; LS, SS, Large and small snow; SP, sector plate; PD, planes dendrite.

Table 3

Equations used to Convert Particle Area (A) to Melted Diameter (D), $D = aA^b$ Units; mm, mm^2

Particle Type	a	b	Breakpoint (mm^2)
Rain	1.13	.5	-
Wet Snow	1.13	.5	LE.78
" "	1.08	.32	Between
" "	.52	.40	GT 62
Large and Small Snow	.52	.40	GT.001
Bullet-Rosettes	.50	.39	LE.21
" "	.61	.51	GT.21
Columns	.42	.35	LE.16
"	.52	.46	GT.16
Needles	.42	.35	-
Plate Family	.46	.32	LE.45
" "	.56	.58	GT.45
Agg. Plates and Dendrites	.39	.31	LE.25
" " " "	.44	.40	GT.25
Dendrite Family	.39	.31	LE 1.07
" "	.38	.48	GT 1.07

6. COMPARISON OF RESULTS

It is always of interest as well as a certain measure of progress, or lack thereof, to compare results between different ways of sensing a quantity or of analyzing data. A few examples of such comparisons are given below from a very limited set of available data.

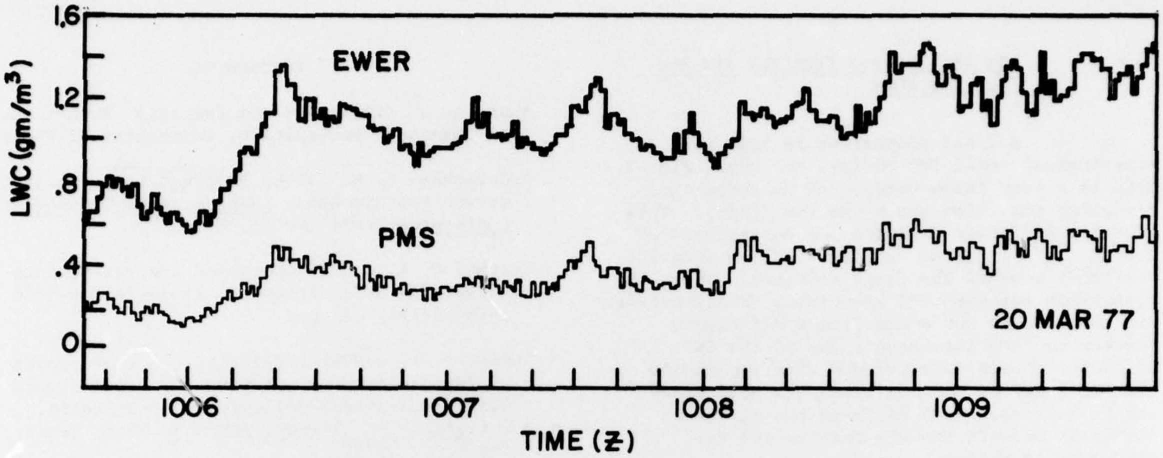


Figure 3. Comparison between LWC derived from PMS particle data and that from the EWER instrument.

6.1 **Comparison between the 1D, 2D Input**

Comparison of results between the several ways of analysis outlined above can be made. An intercomparison between the measured total particle count computed IWC (M) and radar reflectivity (Z) is given in table 4. The results from two completely separate instruments are shown here the, 1D and 2D, as well as three different ways of computing M and Z from the 2D device.

6.2 **Comparison of 1D M and Z Results with Remote Radar Measurements**

An example of good agreement between PMS derived Z values and ground radar values are given by Cunningham (1976). The agreement was better in the matching of the details of Z structure than perhaps in absolute value, however, the difference converted, for instance, to L to D error would be small. Comparison between derived Z and radar measured Z made on the 20 March 77 near Wallops Island VA illustrates both fair agreement and the necessity to consider the contributions of particles larger than the probe can properly sample. Table 5 compares the M and Z values computed from the 1D device as well as values obtained for an extrapolated distribution (M_∞, Z_∞). The distribution is extrapolated using as a guide the shape of the nondimensional distribution function. The remotely measured values of radar reflectivity (Z_R) were obtained from a carefully calibrated ground radar. Note the Z_R values lie as they should between Z and Zoo on most of the passes.

Table 4
Comparison of Four Derivations of Parameters of a Particle Distribution

(Data Taken from 20 March 77 Flight of C-310 10:18:22 - 10:18:57)

	N_T #/m^3	M_3 g/m^3	dBZ
1D	1890	.97	36
2D, HFP[(1)]	2220	.93	35
2D, Max. Length	2417	1.25	37
2D, Area	2288	.98	35

(1) Data processed in a similar way as 1D data.

Table 5
C-130 Data from 20 March 77 Wallops Is Va.
Snow Type Aggregates of Plates and Dendrites

Start Time Z	Alt Km	Temp °C	M (1) g/m^3	dBZ(1)	dBZ_R (2)
1006	6	-17	.22 - .25	17 - 24	23
0951	4.9	-13	.37 - .39	22 - 24	24
0947	4.9	-13	.23 - .28	21 - 27	24
1015	4.9	-13	.27 - .39	22 - 31	33
0937	4.1	-10	.19 - .23	21 - 25	25
0933	3.9	- 9	.23 - .27	22 - 25	26
1028	3.9	- 9	.24 - .30	22 - 27	27
0917	3.0	- 5	.08 - .26	19 - 35	29

(1) First number value calculated from PMS data, second number calculated after extrapolating distribution to infinite particle size.

(2) Value measured by remote ground based radar, SPANDAR.

6.3 The LWC Derived from the PMS and from the EWER

A final comparison is made with an experimental total IWC device, the EWER, Fig. 3. This is a very large version of an evaporator described some time ago by Ruskin (1965). This recent version was designed and constructed by Durran (1976). These data from this new device represent some of the first obtained. There is remarkable agreement of structural detail between the two records but a consistent difference between the absolute magnitudes of the IWC. A different choice of snow type when applied to the PMS analysis can minimize this difference but in this case will decrease the agreement (table 5) between the PMS results and the ground radar values.

7. SUMMARY

Necessary conversion factors and software have been developed to allow analyses of both the 1D and 2D PMS probe data in snow. The 1D analysis procedures have become fairly routine at AFGL, the 2D procedures are still experimental. Because of the complex nature of the 2D data edit programs are necessary to "clean up" the raw 2D data to allow the more sophisticated analysis programs to output meaningful information. A single comparison between the results calculated from simultaneously obtained 1D and 2D data were good. Radar reflectivity values (Z) calculated from the PMS 1D probe information were compared with simultaneously measured Z_R values obtained from a remote radar. The comparison was good, as a careful, but appropriate, choice of snow type was made and after allowance was made for the non sampled large particles. Comparison of the computed PMS water content was made with the output of an experimental LWC device. The average value of these two outputs did not agree but there was remarkable agreement in the details of the structure in the water content-time plot.

8. ACKNOWLEDGMENT

Many people from several organizations have been involved in gathering and processing the data discussed here. These efforts are greatly appreciated. In the area of analysis I wish to thank Fred Kaplan of Digital Programming Services for his creative efforts in developing the 1D and 2D software and Shu-lin Tung of Environmental Research Technology, Inc. for her diligent work in collecting and processing the varied particle size/mass data and for developing nominal ECR relations for various crystal types.

REFERENCES

Auer, A. H. (1971) Interim Progress Report No. 4 to Bureau of Reclamation, University of Wyoming.

Cunningham, R. M. (1976) Progress in precipitation growth measurements, International Cloud Physics Conference, AMS, Boston, 653-657.

Durran, D. A. (1976) Operation and Maintenance Manual for EWER, Aerospace Report # TDR-0076 (6550-19)-1, 111 pp.

Gayet, J. F. (1976) Physics of the measurement of the dimensional spectrum of cloud droplets using Knollenberg collectors. PhD Thesis, University of Clermont-Ferrand, 77pp, Translated for AFGL, 1977).

Heymsfield, A. J. and Knollenberg, R. G. (1972) properties of cirrus generating cells, J. Atmos. Sci., 29:1358-1366.

Heymsfield, A. J. (1976) Utilization of aircraft size spectra mea surements and simultaneous doppler radar measurements to determine the physical structure of clouds. 17th Conference on Radar Meteorology (Seattle) AMS, Boston, pp 206-213

Joss, J. and Waldvogel, A. (1969) Raindrop size distribution and sampling size errors, J. Atmos. Sci., 26:566-569.

Knollenberg, R. G. (1970) The optical array: An alternative to scattering or extinction for airborne particle size determination. J. Appl. Meteor. 9:86-103.

Knollenberg, R. G. (1972) Measurements of the growth of the ice budget in a persisting contrail, J. Atmos. Sci., 29: 1367-1374.

Knollenberg, R. G. (1975) The response to optical array spectrometers to ice and snow: A study of probe size to crystal mass relations, ARCRL-TR-75-0494 Air Force Cambridge Research Laboratories, 69pp.

Knollenberg, R. G. (1976) The response of optical array spectrometers to ice and snow: A study of 2D probe area-to-mass relationships, AFGL-TR-76-273, Air Force Geophysics Laboratory, 31pp.

Magono, C. and C. W. Lee (1966) Meteorological classification of natural snow crystals. J. Fac. Sci. Hokkaido University, Ser. 7, 2, 320-335.

Ruskin, R. E. Humidity and moisture, Vol 1, principles and methods of measuring humidity in gases. Ch 66. Reinhold, p. 643-650.

Sekhon, R. S. and Srivastava, R. C. (1970) Snow size spectra and radar reflectivity, J. Atmos. Sci. 27:299-307.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

14

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFGL-TR-78-0102	2. GOVT ACCESSION NO. 3. RECIPIENT'S CATALOG NUMBER: 9 Scientific interim rept.,
4. TITLE (and Subtitle): 6 ANALYSIS OF PARTICLE SPECTRAL DATA FROM OPTICAL ARRAY (PMS) 1D AND 2D SENSORS.	5. TYPE OF REPORT & PERIOD COVERED: Scientific. Interim.
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 Robert M. Cunningham	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Geophysics Laboratory (LY) Hanscom Air Force Base Massachusetts 01731	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 17 627A0005
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Geophysics Laboratory (LY) Hanscom Air Force Base Massachusetts 01731	12. REPORT DATE: 25 April 1978 11 12
	13. NUMBER OF PAGES: 6 8p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Reprinted from Preprint Volume: Fourth Symposium on Meteorological Observations and Instrumentation, Apr. 10-14, 1978, Denver, Colo. Published by the American Meteorological Society, Boston, Mass. pp 345-350

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

ice water content
cloud particles
precipitation particles
hydrometeor measurements from aircraft
snow
ice crystals
automatic shape characterization

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

For several years, the Air Force Geophysics Laboratory has flown a full set of PMS (Particle Measuring Systems, Inc.) sensors aboard both a C-130 (Air Force operated) and a Learjet (contractor operated). Many flights have been made* through U. S. East Coast deep cyclonic systems, as well as into tropical cloud systems. A full variety of hydrometeor types has been encountered. Many of these aircraft data samples were accompanied by measurements of the radar reflectivity factor by a ground radar just ahead or behind the aircraft, as well as measurements of the water content and

next page

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

* with PMS sensors

409 578

particles by other airborne instrumentation.

The analysis procedures used to reduce the voluminous particle data collected by the PMS sensors are described, relatively straightforward procedures in the case of the one dimensional data, and more complex procedures for the two-dimensional shadow graphs. The results of some of this analysis are compared with direct and indirect measurements from other sensors.